User Guide to the **STAFF** measurements in the Cluster Active Archive (CAA)

Version 3

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1 Introduction

This document provides a brief outline of the data archiving from the STAFF experiment on Cluster in the ESA Cluster Active Archive (CAA).

First, the CLUSTER STAFF experiment is briefly described, including its operations and failures, as well as the calibration and processing procedures of the measurements. Afterwards the key science measurements and datasets are described including some general warnings and recommendations for the users of the STAFF datasets. All STAFF datasets available on the CAA are listed in appendix A.

NOTE: the present document describes the data as of 22 April 2011. Since the CAA is an active archive, new datasets are added and existing datasets are updated continuously, and the User Guide will be updated accordingly.

2 Instrument Description

The CLUSTER STAFF instrument comprises a tri-axial search coils magnetic sensors (0.1Hz- 4 kHz frequency range), and two on-board wave analysers: a magnetic waveform unit (STAFF-SC) and a wave spectrum analyser (STAFF-SA). The latter calculates the complete spectral matrix for the 3xB (magnetic field) + 2xE (electric field) wave components. The wave electric fields, measured by the four spherical EFW sensors, are transmitted to and analysed by the STAFF-SA electronics. For more details about instrument description, see documents [1], [2], [3] and [4].

2.1 The Magnetic Waveform Unit

The magnetic waveform unit (STAFF-SC) is made of various sections to fulfil different filtering and waveform digitalisation, output interface and on-board calibration (for the whole STAFF experiment).

The three magnetic components of the magnetic field (B_x, B_y and B_z), at the output of the search coil preamplifiers are simultaneously filtered in either 0.1–10Hz or 0.1–180Hz bandwidths depending on the spacecraft telemetry mode (NBR Normal Bit Rate and HBR High Bit Rate, respectively). Then, the three components are simultaneously digitised by 16 bits sampling at 25 or 450 Hz according to the previous telemetry modes. STAFF and EFW waveforms are sampled simultaneously and synchronized by the Digital Wave Processor (DWP). Note that EFW and STAFF filters have been identically designed for further combined electromagnetic waveform data analysis.

2.2 The Spectrum Analyser

The Spectrum Analyser (STAFF-SA) is designed to perform the complete auto- and cross - correlation matrix of 5 wave components (B_x, B_y, B_z, E_y, E_z) over a frequency range superior to 9 octaves at a high rate. The 8Hz–4k Hz frequency band is divided into 3 logarithmically distributed frequency sub-bands (A: 8-64Hz, B: 64-512Hz and C: 512-4096Hz), each one being divided into 9 frequency channels. The analysis band is therefore divided into 27 frequency bands, logarithmically spaced.

2.3 Instrument Coordinate System

STAFF level 2 and level 3 data products are given in despun coordinate systems, as detailed below.

Nevertheless, STAFF-SC level 1 wave form (DWF) data are given in the instrument reference frame, in order to keep all available information. For instance the onboard compression of the waveform data is performed on each individual component, i.e. in the instrument reference frame; this allows evaluating the compression quality. This reference frame is called SSW6RF (STAFF Sensor WEC6 Reference Frame), and has been chosen to be the same as EFW instrument coordinate system in the spin plane (at 45° of the satellite body built reference frame); the third component, orthogonal to the 2 others, is parallel to the spacecraft X axis, parallel to the spin axis, at the first order of precision. This is shown on the figure which follows.

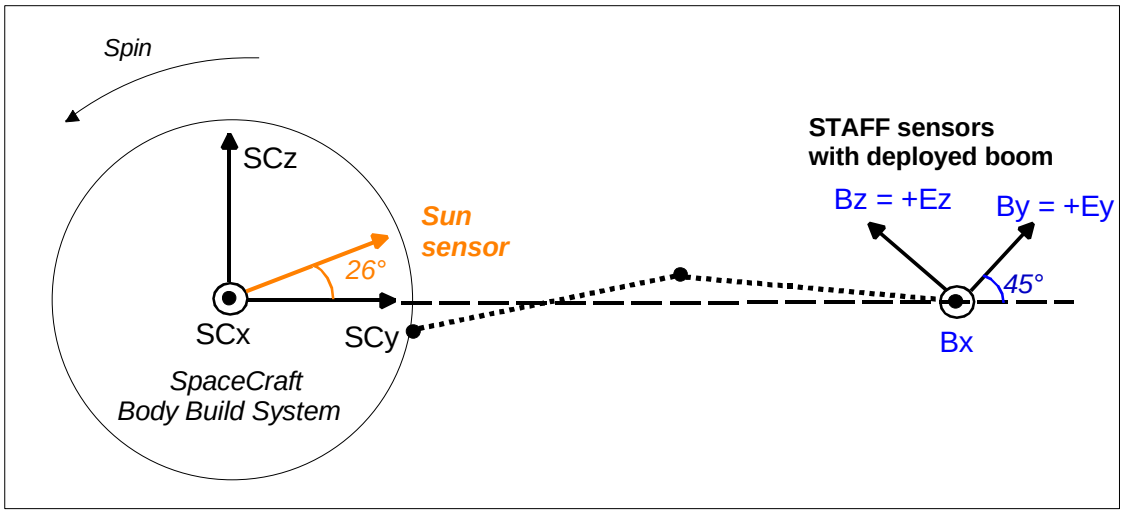


Figure 1: STAFF antenna reference frame.

For STAFF-SC, level 2 data (CS), products coming from the wave form data are given in GSE.

For STAFF-SA data, the level 2 products are given in ISR2 (inverse of SR2: Spin Reference 2), close to GSE (Geocentric Solar Ecliptic). ISR2 has been chosen instead of GSE usually used, as there are only 2 electric components, any transformation to a coordinate system which is not in the satellite spin plane needs to do the hypothesis E.B=0. We decided not to apply this assumption as the STAFF SA level 2 data are the most complete data set of this part of the experiment to be kept in CAA.

In the case of STAFF-SA L3 delivery products (Polarization and Propagation Parameters) the coordinate system is the meaningful one for such data, the MFA (Magnetic Field Aligned). There is no risk to loose information, as it is always possible to recalculate these parameters, starting from level 2 data (Spectral Matrix).

For the definition of GSE, SR2, MFA see e.g. the CAA metadata dictionary, §7.7 (http://caa.estec.esa.int/documents/DataDic.pdf)

3 Instrument Operations

Different operational modes have been applied, mainly depending on the bit rate, either normal (NBR) or high (HBR). The complete description of the different possible modes is given in [2] and [4]. The main characteristics of the most common modes for the waveform and the spectrum analyser are given below in Table 1 and Table 2. The magnetic (STAFF SC) and electric (EFW) waveform frequencies are low-pass filtered in the same way and are sampled simultaneously as commanded by DWP experiment. Other modes are nearly never run, at the exception of the commissioning phase or special tests. Other exception, a calibration mode is run once per orbit.

	STAFF-SC (wave form)	STAFF-SA (Spectrum Analyser)			
Bit Rate	Frequency Range	Frequency Range	Data	Resolution	Modes Name
Normal Bit Rate	0.1-10 Hz	8 Hz-4 kHz	PSD SM	1s 4s	NM1; NM1'b
High Bit Rate	0.1-180 Hz	64 Hz – 4kHz	PSD SM	0.125 or 0.25s 1s	FM1 or FM2; FM3b

Table 1: STAFF modes main characteristics as a function of Telemetry mode.
PSD: Power Spectral Density and SM: Spectral Matrix.

The content of STAFF-SA data depends both on the bit rate (frequency range and time resolution, cf Table 1) and the Whisper mode (cf Table 2). The Whisper active sounding lasts for a few seconds (about 3 seconds) usually every 52 or 104 seconds. DWP synchronises perfectly STAFF-SA and Whisper operational modes so that the sounding effect (whisper sounder on) is always within one sample only for 4s resolution STAFF-SA spectral matrix. There is no calculation of the spectral elements comprising electric field data during those 4 seconds. There are no electric field data when whisper is active; this is why one can see white lines or data gaps on electric dynamic spectra (see e.g. figure 5).

WHISPER MODE	STAFF-SA components	STAFF SA Mode Names
active	3 x B	NM1; FM1; FM3
passive	3 x B + 2 x E	NM1'b; FM3b

Table 2: Main STAFF SA modes as a function of Whisper experiment mode, active or passive.

STAFF SA electric components may be affected by the EFW preamplifier failure on some of the spacecraft (see table 3). The STAFF SA onboard despin doesn't permit to get rid of this problem and thus the 2 despun components telemetry data are affected. After the failure, the electric antenna may be saturated, but once EFW has commanded the failed probe into density mode, i.e. set the potential to V=0, the quality is good again, but the sensitivity is decreased. This is detailed in § 6.3.

Spacecraft number	Probe number	Date of failure	Density mode implementation
1	1	2001-12-28	2002-01-27
1	4	2009-10-14	2009-11-28
2	1	2007-05-13	2007-06-23
3	1	2002-07-29	2002-08-09

Table 3: Dates of failure of EFW components and date of partial recovery (density mode implementation).

4 Measurement Calibration and Processing Procedures

For details on the calibration techniques and results, see document [5]. To summarise, in what concerns magnetic field fluctuations:

- The state of the instrument has not varied with time, at the date of April 1st, 2011.
- A difference of 10 % in the transfer function of S/C 1 with respect to other spacecraft underestimates the amplitude of the magnetic field fluctuation below 8 Hz on this spacecraft.
- A general under-estimation of about 8% of the magnetic field fluctuations with respect to FGM has been noticed.
- Those differences are now understood, and should be corrected soon and before delivery of Calibrated Wave Form (CWF) data product.

Figures 2.a and 2.b summarize the processing procedures.

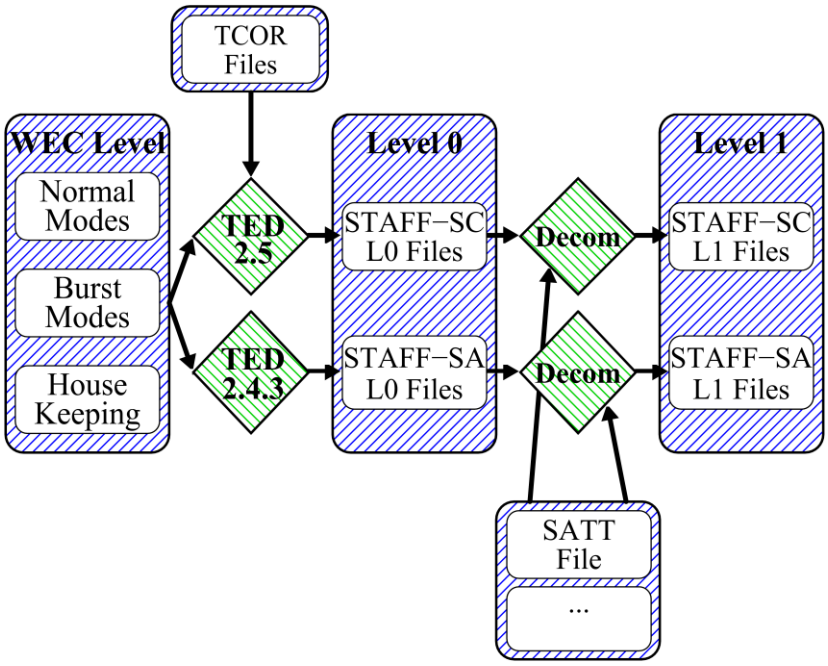


Figure 2.a: processing chain to obtain Level 0 and Level 1.

4.1 Production of Level 0 products and Timing Issues

TED software produced by the DWP team is applied to WEC data provided by ESOC in order to get Level 0 (L0) files. At this stage, STAFF science data are separated into two different data sets (STAFF-SC and STAFF-SA) and time tagged thanks to the WEC Housekeeping data and TED. The **TED version 2.5 is run to extract STAFF SC** data files to get the best possible time accuracy by activating the option using **TCOR** files in order to reach a time accuracy of the order of some microseconds, which is important mainly for wave data in high bit rate for inter spacecraft comparisons.

The comments which follow only concern a future utilisation of STAFF waveform data: *In the case of simultaneous utilisation of EFW waveform, the user should verify that the same option has been chosen for those concerned data set production by EFW team.*
As there are some gaps in TCOR files, all data are not time-corrected. For the moment, there are no flag in the data to inform the users when data are not corrected.
Presently this concerns only the uncalibrated waveform data, as calibrated spectra have a ~10 s time resolution. In the next future, a status on time correction availability will be given in a new version of DWF and in the the calibrated waveform data files.. For the moment, the users can check the TCOR CAVEAT files provided by DWP.

For **STAFF SA, TED version 2.4.3** is used (an accuracy of sub-millisecond is not needed as the best STAFF SA time resolution in HBR is only 125 ms). This version insures an accuracy of 4 ms.

4.2 Production of Level 1 products

The decommutation, to go from L0 to Level 1 (L1), is done by software written in LPP, previously CETP. Data are decompressed. See documents [6] and [7] for details.
Depending on the data set, some status informations are given.
Only STAFF SC level one data are delivered to CAA, namely DWF (see § 5.1).
For STAFF-SC data, in addition to the standard STAFF science data status, the spin phase is computed from the Sun Reference Pulse (SRP) and added in the L1 file in order to permit further transformation of the data in any reference frame. The quality of the phase determination, depending on the presence or not of the SRP information in the auxiliary data, is given in the status word.

The Status is a word of 11 ASCII characters, each depending on one different factor. The status word is composed as follows:

Step in cal	EFW Y	EFW Z	Mode SA	Mode SC	Despin SA	WHISPER	Calibration	EFW sweep	Compressio	Phase

Table 4: STAFF status word
The value of each character is explained in appendix C.

4.3 Production of Level 2 and Level 3 Products

Figure 2.b. below shows the processing chain for getting level 2 and level 3 products, from the level 1 described above. Details on the different products are given in the next section.

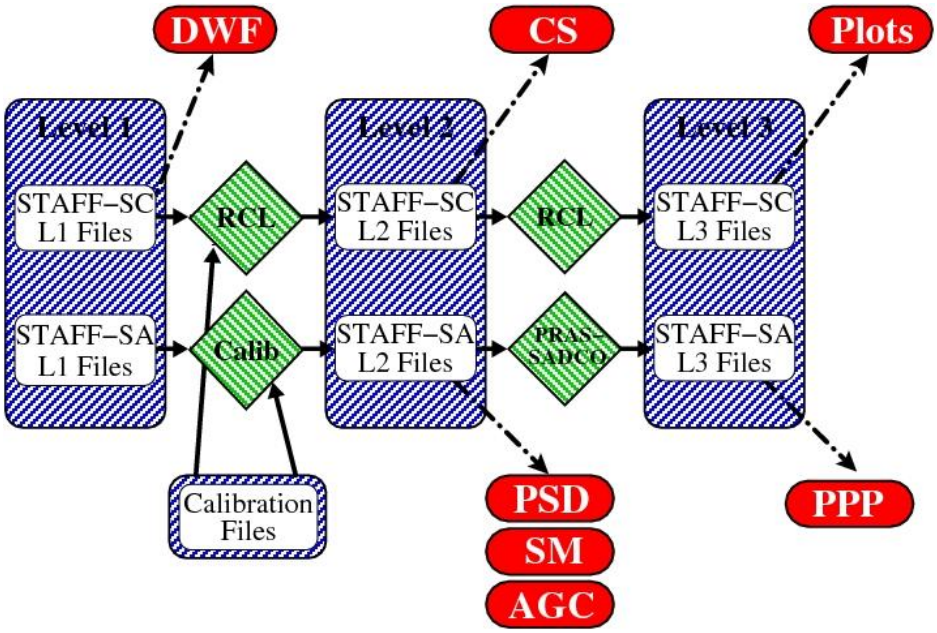


Figure 2.b: processing chain to obtain Level 2 and 3 from Level 1.

5 Key Science Measurement and Datasets

Level 1 STAFF-SC products are delivered in the STAFF Sensor WEC6 Reference Frame (SSW6RF). Level 2 STAFF-SC products are delivered in GSE coordinate system. Level 2 STAFF-SA products are delivered in ISR2 system, where 'I' stands for inverted spin axis. Level 3 STAFF-SA products are delivered in Magnetic Field Aligned (MFA) coordinate system. (see paragraph 2.3)

5.1 Level 1 STAFF-SC DWF (Decommutated Waveform)

The DWF data are given in telemetry counts in the SSW6RF frame and are stored in the archive as reference data for the case of any reprocessing, in particular in case of data re-calibration. This dataset contains the maximum of information for any further data processing: status, phase, compression error level if any, the best time accuracy. A new version 4 will incorporate the time of start of the telemetry data packets, time at which TCOR is applied.

Supporting data and data are time series data depending on the variables Time__C?_CP_STA_DWF_NBR/HBR.

Supporting Data are:
Status__C?_CP_STA_DWF/NBR/HBR: described in table 4 and appendix C.

Name	STAFF-SC status
Significant Digits	11

Phase_Angle_SC_C?_CP_STA_DWF_NBR/HBR

Name	Phase Angle
Units	Degree
Significant Digits	5

MaxCompError_xyz_Instrument__C?_CP_STA_DWF_NBR/HBR: described in appendix D

Name	Maximum compression Error
Property	Vector
Sizes	3
Units	TM counts
Significant Digits	4

Data: B_vec_xyz_Instrument_C?_STA_DWF_NBR/HBR

Name	Cluster? , NBR/HBR Magnetic Field Decommutated Waveform
Property	Vector
Sizes	3
Components	Bx, By, Bz
Units	TM counts
Significant Digits	5

It is intended to deliver calibrated waveform data in physical units (nT) when the new calibration algorithm is finished and tested. This can be implemented on continuous data set (presently it is done on a defined and limited number of data points due to the frequency dependant transfer function and the successive use of Direct and Inverse Fourier Transforms). In the mean time, the user should rather use calibrated spectra.

5.2 STAFF-SC SPECTRO (3 hours routine plots)- QUICKLOOKS

Routine plots produced at LPP are delivered to CAA. Those plots are QUICKLOOKS for browsing purposes. Each one contents dynamic spectra of the component parallel to the spin axis, for the 4 spacecraft, for 3 hours of data. Data in NBR and HBR telemetry mode are on different plots. They can help selecting a shorter time period to analyse or plot. An example is given in Figure 3.

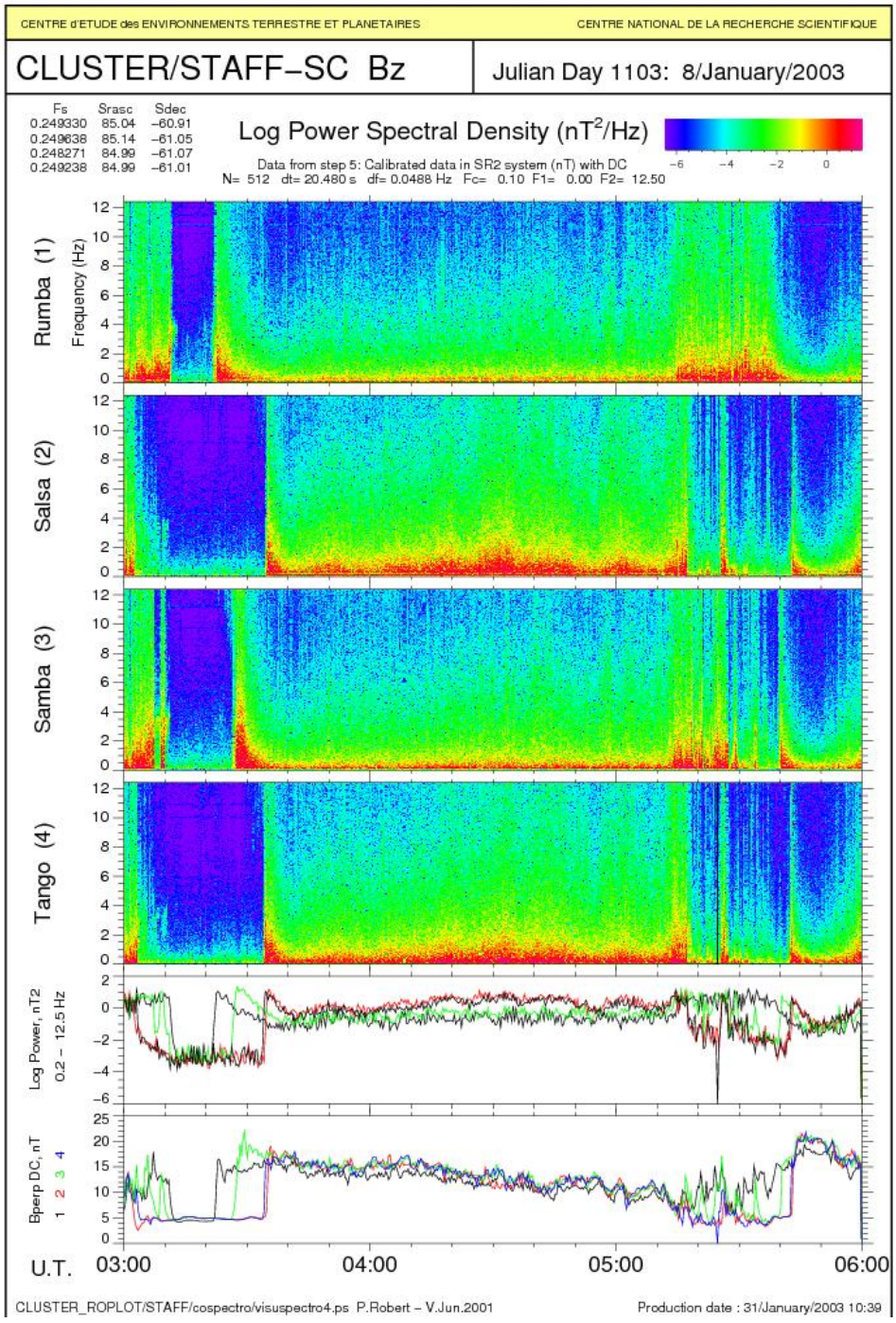


Figure 3: Example of quicklook plot (successive crossings of the bow shock).

5.3 STAFF-SC CS (Calibrated Spectra)

These spectra data are given in nT in the GSE frame of reference. The calibrated complex spectra frequency/time resolutions are ~0.098Hz x 10.24s in NBR and ~0.109Hz x 9.10s in HBR ($\Delta t.\Delta f = 1$). As the spectra are complex, Inverse Fourier Transform can be performed without loss of information. With some appropriate wave analysis dedicated software, the polarisation and propagation parameters can be obtained in the M. F. A. (Magnetic Field Aligned) frame of reference using the FGM data that are available at CAA (5VPS or SPIN). An example of plot obtained with CS data is given on figure 4. Note that the STAFF SC magnetic waveform data at low frequency (around 0.25 Hz) may contain some remnant of the spin signal which can become very strong around perigee, in strong magnetic fields (see § 6).

Supporting data and data are time series data depending on the variables Time__C?_CP_STA_CS_NBR/HBR.

Supporting Data are:
Frequency__C?_CP_STA_CS_NBR/HBR

Name	Frequency bins
Sizes	128
Units	Hz
Significant Digits	4

Data: Complex_Spectrum_C?_STA_CS_NBR/HBR depend on time and frequency

Name	Components of the Magnetic Field Complex Spectrum
Property	Vector
Sizes	128, 2, 3
Components	Re, Im
Units	nT
Significant Digits	4

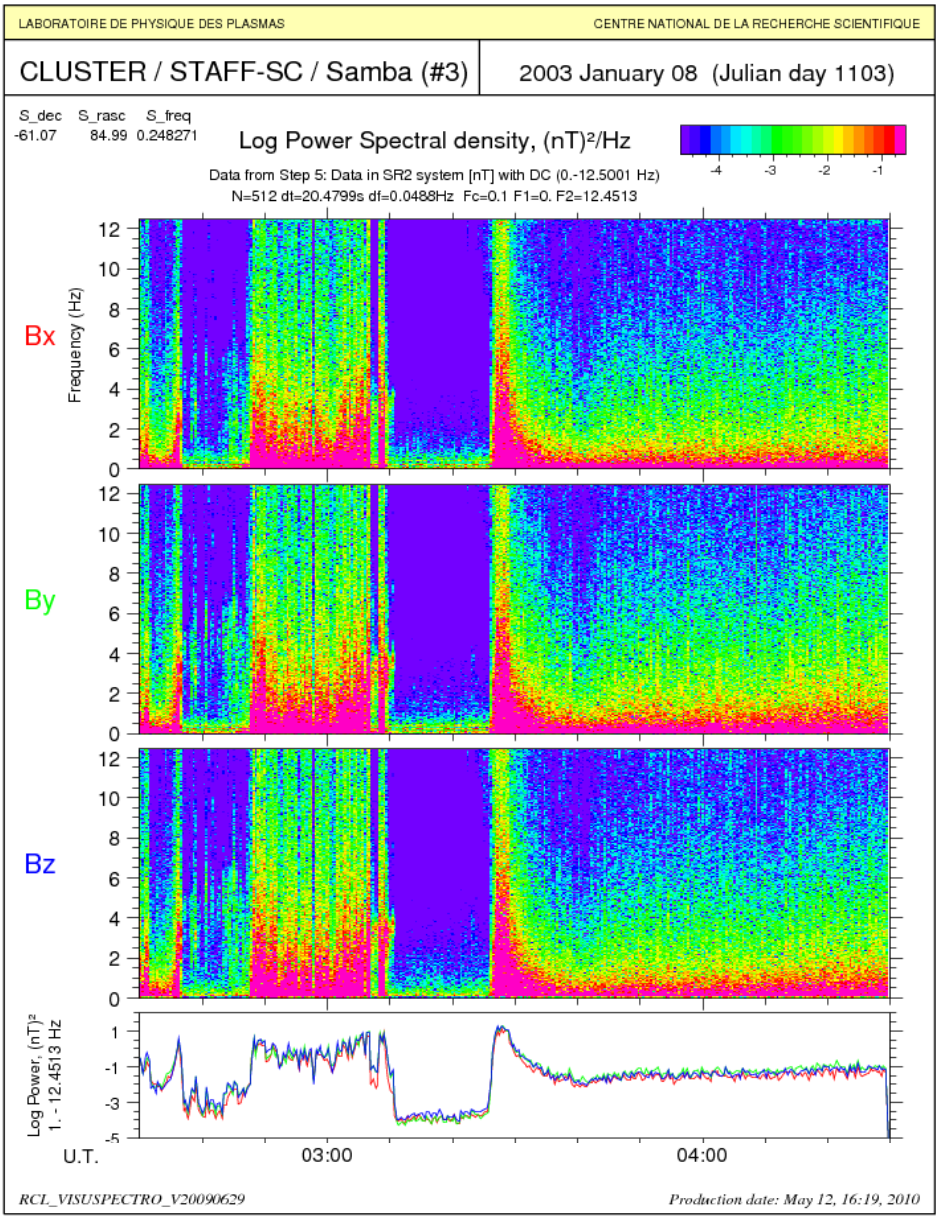


Figure 4: Example of plot for 3 components obtained from CS data (Zoom of Figure 3).

5.4 STAFF-SA PSD (Power Spectral Density)

The Power Spectral Densities values for the magnetic and the electric field are the diagonal term of the Spectral Matrix:

$$\begin{pmatrix} B_x^2 & B_x.B_y^* & B_x.B_z^* & B_x.E_x^* & B_x.E_y^* \\ B_y.B_x^* & B_y^2 & B_y.B_z^* & B_y.E_x^* & B_y.E_y^* \\ B_z.B_x^* & B_z.B_y^* & B_z^2 & B_z.E_x^* & B_z.E_y^* \\ E_x.B_x^* & E_x.B_y^* & E_x.B_z^* & E_x^2 & E_x.E_y^* \\ E_y.B_x^* & E_y.B_y^* & E_y.B_z^* & E_y.E_x^* & E_y^2 \end{pmatrix}$$

Those parameters are given in nT^2Hz^{-1} for the magnetic components (B_x^2, B_y^2 and B_z^2) and in $mV^2m^{-2}Hz^{-1}$ (E_x^2 and E_y^2) for the electric ones. Dynamic spectra can thus be deduced for any component of the electromagnetic or electrostatic waves in the 8 Hz – 4 kHz frequency range. The electron gyrofrequency is covered by the STAFF frequency range on the complete orbit or a major part of it (i.e. except close to the perigee).

Note that the time resolution is better for the PSD than for the complete Spectral Matrix elements (see Table 1), varying from 0.125 or 0.25 ms in HBR to 1 s in NBR. The data, delivered to CAA in ISR2 reference frame, can be transformed into any reference frame, with no hypothesis for the magnetic field components, and with the hypothesis E.B=0 for the electric components (see § 2.3). Figure 5 gives an example of dynamic spectra of E and B field for the 4 Cluster.

Sometimes, mainly when the signal level is very low, there are negative PSD values in the raw data. Those have been replaced by fill values (see § 6).

Supporting data and data are time series data depending on the variable Time__C?_CP_STA_PSD.

Supporting Data are:
Frequency__C?_CP_STA_PSD

Name	Interval centred frequency tag
Sizes	27
Units	Hz
Significant Digits	4

Frequency_BHW__C?_CP_STA_PSD

Name	Frequency bin half width
Sizes	27
Units	Hz
Significant Digits	3

Data are separated into two variables, one for the magnetic components, and another for the electric ones.
BB_C?_STA_PSD depend on time and frequency

Name	Power Spectrum 8-4000 Hz of the B-field components along the ISR2 coordinate axe
Property	Vector
Sizes	27, 3
Components	B_x^2, B_y^2, B_z^2
Units	nT^2Hz^{-1}
Significant Digits	3

EE_C?_STA_PSD depend on time and frequency

Name	Power Spectrum 8-4000 Hz of the e-field components along the ISR2 coordinate axe
Property	Vector
Sizes	27, 2
Components	E_x^2, E_y^2
Units	$mV^2m^{-1}Hz^{-1}$
Significant Digits	3

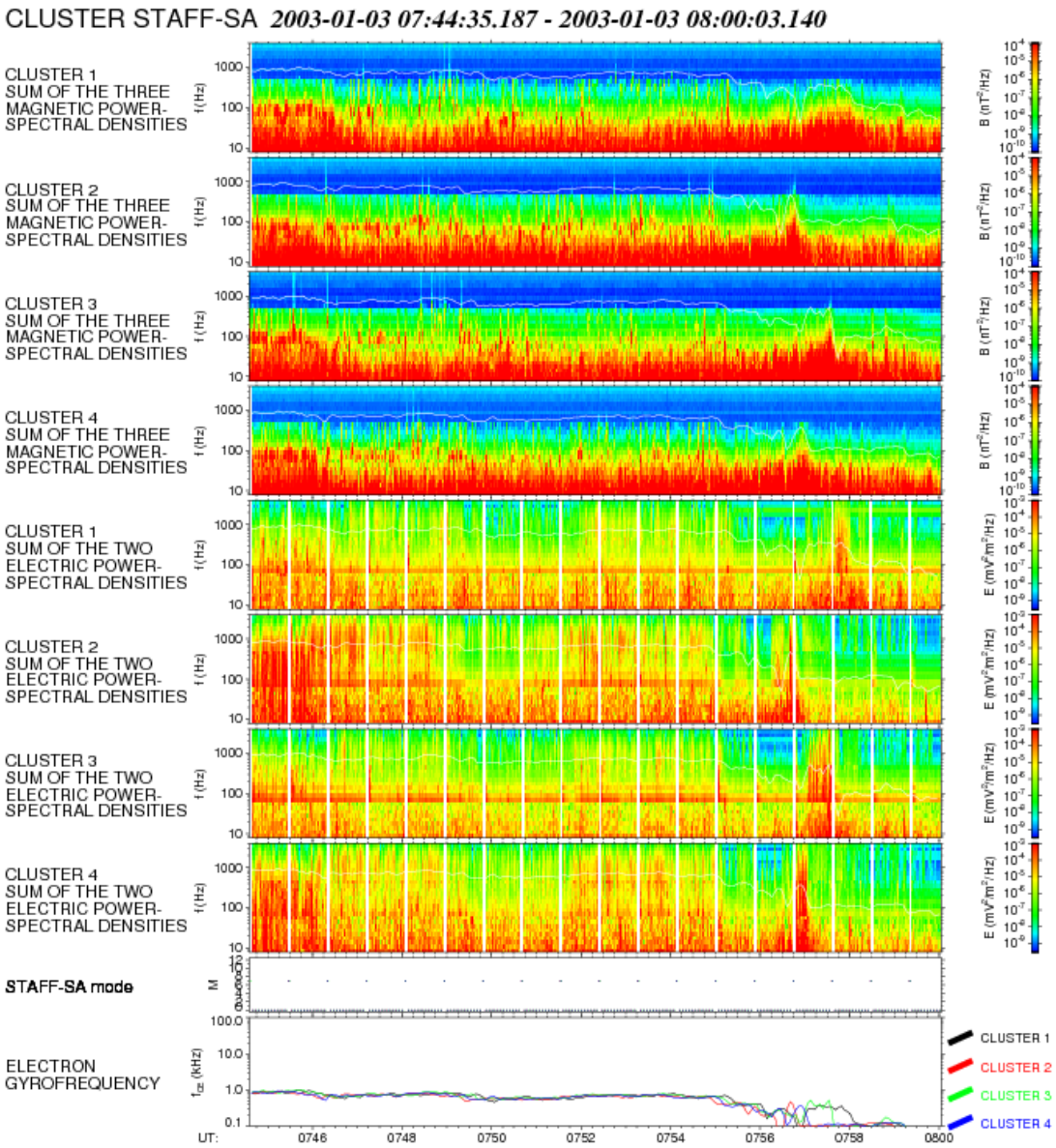


Figure 5: Example of plots of data derived from PSD in the magnetosheath.
B and E power density for the 4 spacecraft.
Experiment mode varies from mode 1 (5 components) to mode 7 (3 x B) when Whisper experiment is active. This explains the white lines on E data

5.5 STAFF-SA SM (Spectral Matrix)

The Spectral Matrix values for the magnetic electric cross-products are:

$$\begin{pmatrix} B_x^2 & B_x.B_y^* & B_x.B_z^* & B_x.E_x^* & B_x.E_y^* \\ B_y.B_x^* & B_y^2 & B_y.B_z^* & B_y.E_x^* & B_y.E_y^* \\ B_z.B_x^* & B_z.B_y^* & B_z^2 & B_z.E_x^* & B_z.E_y^* \\ E_x.B_x^* & E_x.B_y^* & E_x.B_z^* & E_x^2 & E_x.E_y^* \\ E_y.B_x^* & E_y.B_y^* & E_y.B_z^* & E_y.E_x^* & E_y^2 \end{pmatrix}$$

The SM diagonal terms contain three magnetic components (B_i^2) given in nT^2Hz^{-1}, and two electric components (E_i^2) given in $mV^2m^{-2}Hz^{-1}$ (like PSD). The cross-products (B_i x E_j) are expressed in $nT.mV.m^{-1}Hz^{-1}$. From this data set, once in the MFA, wave characteristics (polarisation, ellipticity, direction for propagation etc…) can be retrieved. Those parameters are now starting to be delivered at CAA (see § 5.7).

Note that the diagonal terms values of the matrix are the result of an average over 4 or 8 successive PSD values.

Supporting data and data are time series data depending on the variable Time__C?_CP_STA_SM

Supporting Data are:
Frequency__C?_CP_STA_SM

Name	Interval centred frequency tag
Sizes	27
Units	Hz
Significant Digits	4

Frequency_BHW__C?_CP_STA_SM

Name	Frequency bin half width
Sizes	27
Units	Hz
Significant Digits	3

Data are separated into three variables, one for the magnetic components BB, one for the electric components EE, and one for the BE cross-products:
BB_C?_STA_SM depend on time and frequency

Name	Cross-Spectral matrix of the magnetic field at 27 frequencies from 8 Hz to 4 kHz.
Property	Vector
Sizes	27, 2, 3, 3 !27frequency bins x 2 (Re + Im) parts x (3x3) matrix
Units	nT^2Hz^{-1}
Significant Digits	3

EE_C?_STA_SM depend on time and frequency

Name	Cross-Spectral matrix of the electric field at 27 frequencies from 8 Hz to 4 kHz.
Property	Vector
Sizes	27, 2, 2, 2 !27frequency bins x 2 (Re + Im) parts x (2x2) matrix
Units	$mV^2m^{-2}Hz^{-1}$
Significant Digits	3

BE_C?_STA_SM depend on time and frequency

Name	Electromagnetic Cross-Spectral ExB products at 27 frequencies from 8 Hz to 4 kHz.
Property	Vector
Sizes	27, 2, 3, 2 !27frequency bins x 2 (Re + Im) parts x (3x2) matrix
Units	$nTmVm^{-1}Hz^{-1}$
Significant Digits	3

5.6 STAFF–SA AGC (Automatic Gain Control)

Those parameters are mainly given for control purpose as they are derived from an analogue signal. Nevertheless, it can be useful for plotting large-scale data to study the evolution of the wave global power as a function of any parameters.

The AGC parameters are the average power spectral density in the analogue receivers pass-band derived from the AGC signal. This is measured in the three large pass-band with the same time resolution as PSD.

A parallel (B_z) and a perpendicular (B_{xy}) component to the spin axis are measured for the magnetic field while only the perpendicular one (E_{xy}) is measured for the electric field. There are three AGC values that are given in nT^2Hz^{-1} for the two magnetic AGC (B_z, B_{xy}) and in $mV^2m^{-2}Hz^{-1}$ for one electric AGC (E_{xy}). There is one value per frequency band of the analyser (A: 8-64Hz, B: 64-512Hz and C: 512-4096Hz).

Supporting data and data are time series data depending on the variable Time__C?_CP_STA_AGC

Supporting Data describe the three frequency bands (A, B, C). Each band is defined with the interval centred frequency and the frequency bin half width.
Frequency__C?_CP_STA_AGC

Name	Interval centred frequency tag
Sizes	3
Units	Hz
Significant Digits	4

Frequency_BHW__C?_CP_STA_AGC

Name	Frequency bin half width
Sizes	3
Units	Hz
Significant Digits	3

Data are separated into two variables, one for the magnetic AGC, one for the electric AGC:
B_C?_STA_AGC_ depend on time and frequency

Name	Magnetic AGC
Property	Vector
Sizes	3, 2
Components	B_z, B_{xy}
Units	nT^2Hz^{-1}
Significant Digits	3

E_C?_STA_AGC_ depend on time and frequency

Name	Electric AGC
Property	Vector
Sizes	3
Components	E_{xy}
Units	$mV^2m^{-1}Hz^{-1}$
Significant Digits	3

5.7 STAFF-SA PPP (Polarization and Propagation Parameters)

The PPP give polarisation and propagation parameters for electromagnetic waves. They are derived from singular value decomposition (SVD) of the cross-spectral matrix (SM) using the PRASSADCO program [8] at 27 (or 18 in HBR) logarithmically distributed frequencies between 8 Hz (or 64 Hz in HBR) to 4 kHz. The time resolution is telemetry mode dependant, 1 or 4 s (see Table 1). The SVD method is described in [9].

The parameters derived from the three magnetic components are THSVD, PHSVD, ELLSVD, POLSVD and BSUM. BSUM is the sum of the three magnetic auto-power spectra. When BSUM is inferior to $1.0E^{-09}$ nT^2/Hz, the calculation of the other magnetic dependant parameters is meaningless. The THETA and PHI variables are respectively the **wave vector** polar and azimuthal angles in Magnetic Field Aligned (MFA) coordinate system. POLSVD and ELLSVD stand for the degree of polarisation (between 0 and 1) and the ellipticity (beween -1 and +1), respectivelly The sign of EELSVD indicates whether the waves are right handed (positive) or left handed (negative) polarised.

The parameters **derived from the electric components** are ESUM and PVSIGN. ESUM is the the sum of auto-power spectra of the two electric antennae. PVSIGN is the direction of the

Poynting vector component parallel to the magnetic field. It is given only when E component is valid. Positive (negative) values correspond to a parallel (anti-parallel) Z-component of the Poynting vector. The calculation of PVSIGN is meaningless when BSUM is inferior to $1.0E^{-09}$ nT^2Hz^{-1}, and ESUM to $3.0E^{-09}mV^{-2}m^{-2}Hz^{-1}$. The change of coordinate system has been done using FGM 5VPS data (See FGM user guide for explanation) that is available at CAA.
The FGM 5VPS data set is the magnetic field vector at the resolution of 0.2s (5 Vectors Per Second). Before performing the change of coordinate system, PRASSADCO calculates the mean field direction by averaging the 5PVS data on the time interval relevant to the given SM measurement (1 or 4 s). Then the time attributed to the considered PPP measurement is the time corresponding to the middle of the interval.

Then the user should not worry to find a datation different from SM by half a measurement duration (0.5 or 2 s). For SM, the datation refers to the start time of the measurement interval.

Supporting data and data are time series data depending on the variable Time__C?_CP_STA_PPP.

Supporting Data are:
Frequency__C?_CP_STA_PPP

Name	Interval centred frequency tag.
Sizes	27
Units	Hz
Significant Digits	4

Frequency_BHW__C?_CP_STA_PPP

Name	Frequency bin half width.
Sizes	27
Units	Hz
Significant Digits	3

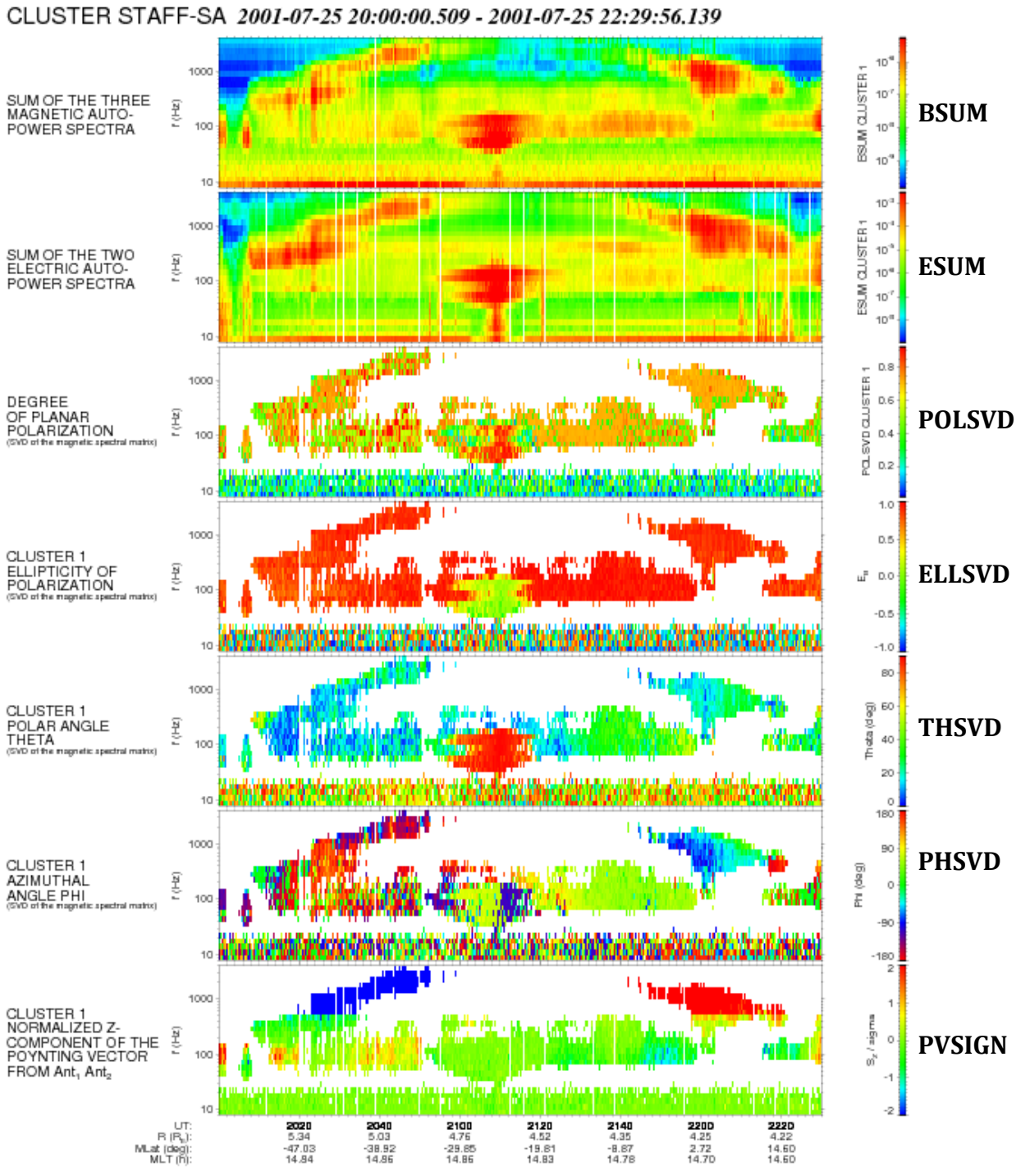


Figure 6: Example of Polarization and Propagation Parameters (PPP) plot. Below a certain power density value PPP are not plotted to help interpretation (here the threshold is 1.0.E-07 nT^2Hz^{-1}*)*

Data are separated into seven variables:

The parameters calculated from the three magnetic components are:

THSVD_mfa__C?_STA_PPP

Name	Polar angle of the direction of propagation in MFA coordinate system (SVD).
Property	Component
Sizes	27
Components	THSVD
Units	Degree
Significant Digits	1

PHSVD_mfa__C?_STA_PPP

Name	Azymuthal angle of the direction of propagation in MFA coordinate system (SVD).
Property	Component
Sizes	27
Components	PHSVD
Units	Degree
Significant Digits	1

ELLSVD__C?_STA_PPP

Name	Ellipticity of the polarization (SVD).
Property	Component
Sizes	27
Components	ELLSVD
Units	Unitless
Significant Digits	2

POLSVD__C?_STA_PPP

Name	Degre of polarization in the polarization plane (SVD).
Property	Component
Sizes	27
Components	POLSVD
Units	Unitless
Significant Digits	2

BSUM__C?_STA_PPP

Name	Sum of the three magnetic auto-power spectra.
Sizes	27
Components	POLSVD
Units	nT^2Hz^{-1}
Significant Digits	2

The parameter calculated from the three magnetic components and the two electric components is PVSIGN__C?_STA_PPP.

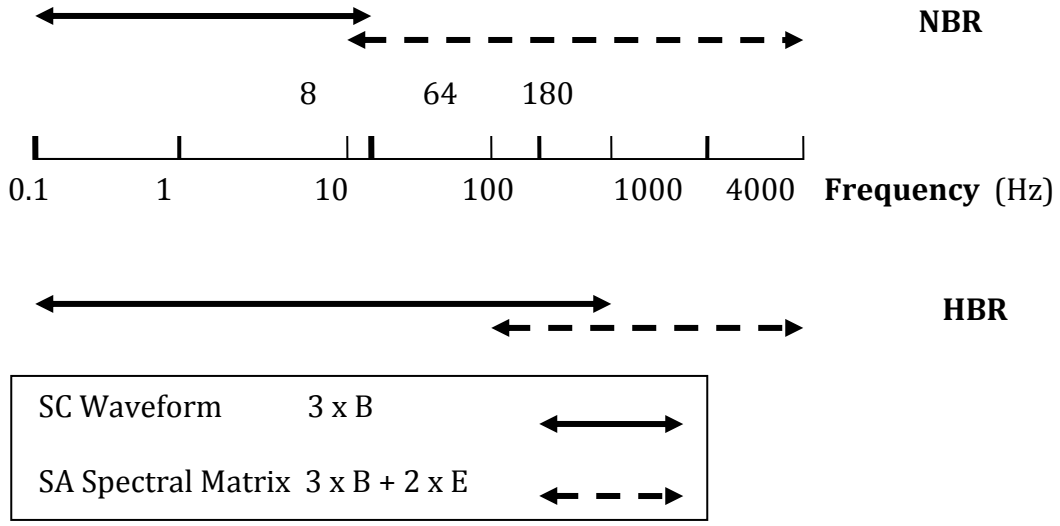
Name	Parallel component of the Poynting vector normalized by its standard deveiation.
Property	Magnitude
Sizes	27
Components	PVSIGN
Units	Unitless
Significant Digits	2

The parameter calculated from the two electric components is ESUM__C?_STA_PPP.

Name	Sum of the two electric auto-power spectra.
Sizes	27
Components	ESUM
Units	$mV^2m^{-2}Hz^{-1}$
Significant Digits	2

6 Recommendations and caveats

The scheme below shows the data availability as a function of telemetry mode and should help choosing a STAFF data set.



6.1 DWF

As the DWF files from STAFF-SC are not calibrated data, they can't be used straightforward by the scientists. These data are time tagged using TCOR option. In the absence of the forthcoming calibrated waveform product (CWF), the most interesting STAFF-SC data are the calibrated spectra.

6.2 Use of CS Data

Those data are calibrated, and can be used with no restriction, the calibration being stable over time. The calibrated spectral measurements are good considering the quality except for the spin frequency where strong noise is observed especially on the X and Y components at perigees.

There may be a remnant of the spin signal close to perigee. Moreover, the perigee has decreased with time. Since ~2008 there is a saturation of the waveform around perigee. There is no warning for the saturation at the moment. This will be added later on. The effect of the spin signal and of saturated data can be seen on the plots below.

A systematic underestimate of the amplitude of the magnetic fluctuations with respect to FGM has been evidenced, of the order of 10%. An additional difference of also ~10% is seen on S/C1 for frequencies < 8 Hz. These differences have now been understood and the calibration functions will be corrected accordingly in the near future (see § 4 and calibration document [5]).

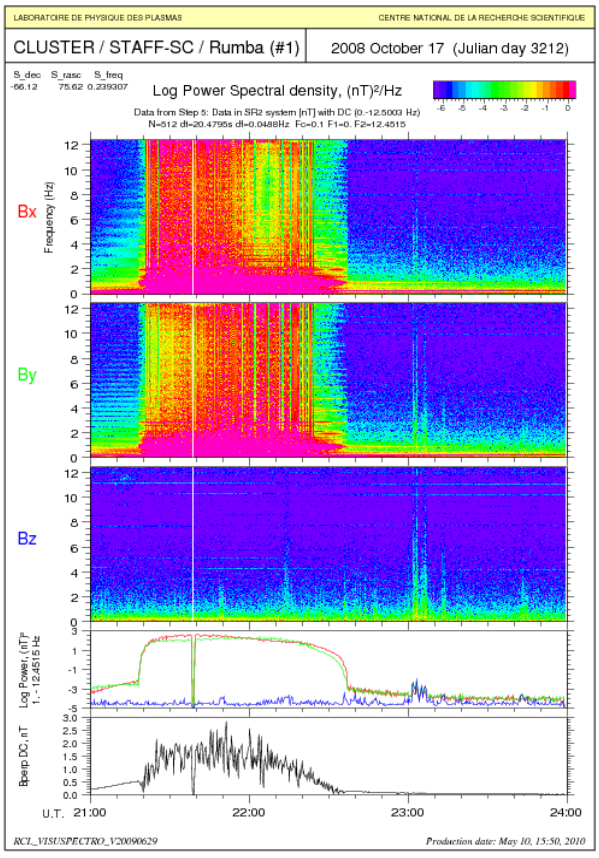


Figure 7: Plot of CS data during a waveform saturation period (DC field > 2000nT).

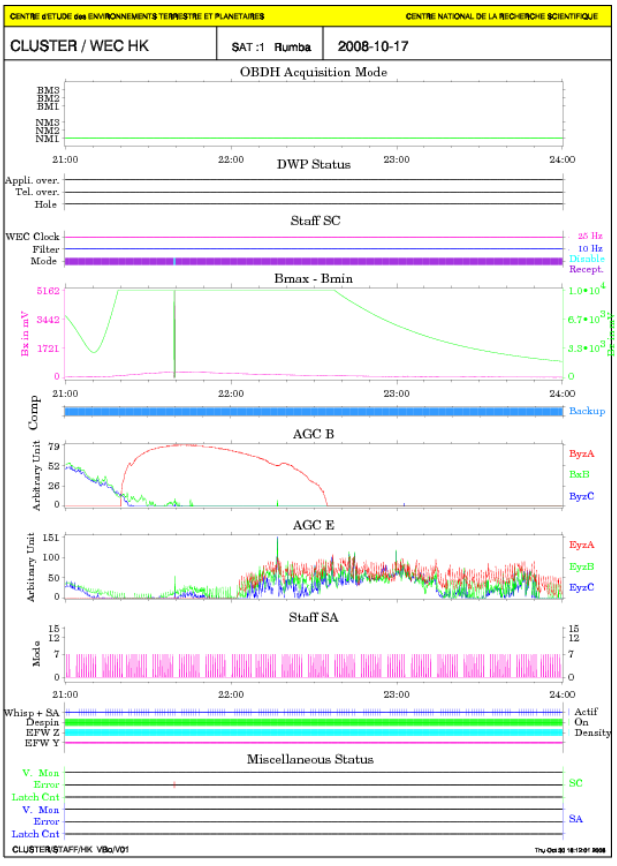


Figure 8: House Keeping data for the same time interval as on Figure. 7. The parameter Bmax-Bmin, amplitude of the analog waveform is above 10 V. Note that the STAFF

SA AGC is saturated too. Search coil data are invalid between 21:20 and 22:40 UT.
Figure 7 and 8 show the effect of waveform saturation at perigee. The quality of the data at the moment can be verified on the LPP web site, looking at the Hiouse keeping plots, at: http://cluster.lpp.polytechnique.fr/accueil/framepa.html.
A flag will be inserted in the CS data in the future. This will permit to eliminate such data from plots, as shown on Figure 9.

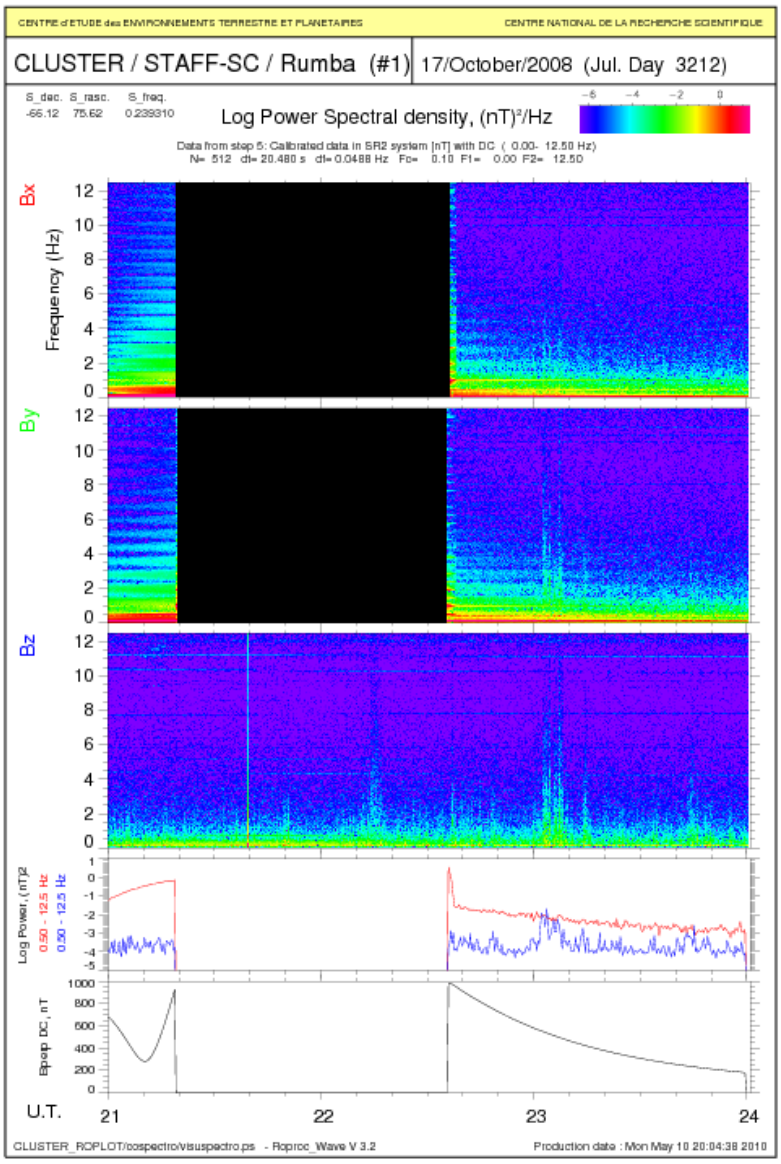


Figure 9: Same plot than on figure 7, using a flag indicating the waveform saturates on a given component.

6.3 Use of STAFF SA products

6.3.1 General considerations applicable to all STAFF SA products

Concerning the use of the parameters calculated from the measurement of magnetic fluctuations**,** for SM and PSD level 2 products, the only warning is the one mentioned above, a possible saturation of the waveform at perigee, which occurs when perigee is low (L≤ ~2).

The Spectral Matrix coefficients are given in a fixed frame of reference on board, taking into account the sun pulse for despinning the data. This constitutes an issue on the validity of the calculation when the sun pulse is not available. This mainly occurs during eclipse periods. That is why a caveat file has been produced as explained below, NOTSRP files.

Caveat 1: NOTSRP

This dataset contains caveats for the PPP, PSD and SM datasets from the STAFF-SA instrument. This caveats dataset provides the users time intervals when no Sun pulse (TSRP) was recorded in the S/C housekeeping data. Note that it can be in eclipse period but not only. During those time intervals only the total power density is meaningful. In particular no PPP data should be used.

Caveat 2: PSDNEG

As already mentioned, when there are PSD negative values, they have been replaced by fill values, and put in this caveat. This dataset contains caveats for the SM datasets from the STAFF-SA instrument. For a given time and frequency are given the PSD negative values that have been replaced in the PSD data product by a fill value. It permits to evaluate the validity of the SM power density value including those negative PSD in its calculation (see § 5.4 and 5.5).

6.3.2 Timing issues

As mentioned in §5.3, one shouldn't worry about a difference of timing between STAFF SA SM and PPP. For a given time interval (1 s or 4 s depending on bit rate mode), SM are dated at the beginning of the interval whereas PPP are date at the middle of the time interval. PPP are time stamped either 0.5 s or 2 later.

6.3.3 Warning considering magnetic field measurements

There may be some 10 % differences between SC1 calibration and other three spacecraft (see §4 and ref [5]). Continuity between STAFF SC and STAFF SA is insured [5]. Nevertheless there are some artefact in the STAFF SA calibration about which the user should be advised, in order to not miss-interpret the data. Figures 10 and 11 show superimposition of magnetic spectra for different signal intensities, for SC 1 and SC 4 respectively. One can see that some fluctuations of the noise level of the experiment do propagate whatever the intensity of the signal. The affected frequencies are below 18 Hz for S/C 1 and below 35 Hz for S/C 4. S/C 2 and 3 are under study. Interferences are hidden for strong enough signal (see e.g. interference at 70 Hz).

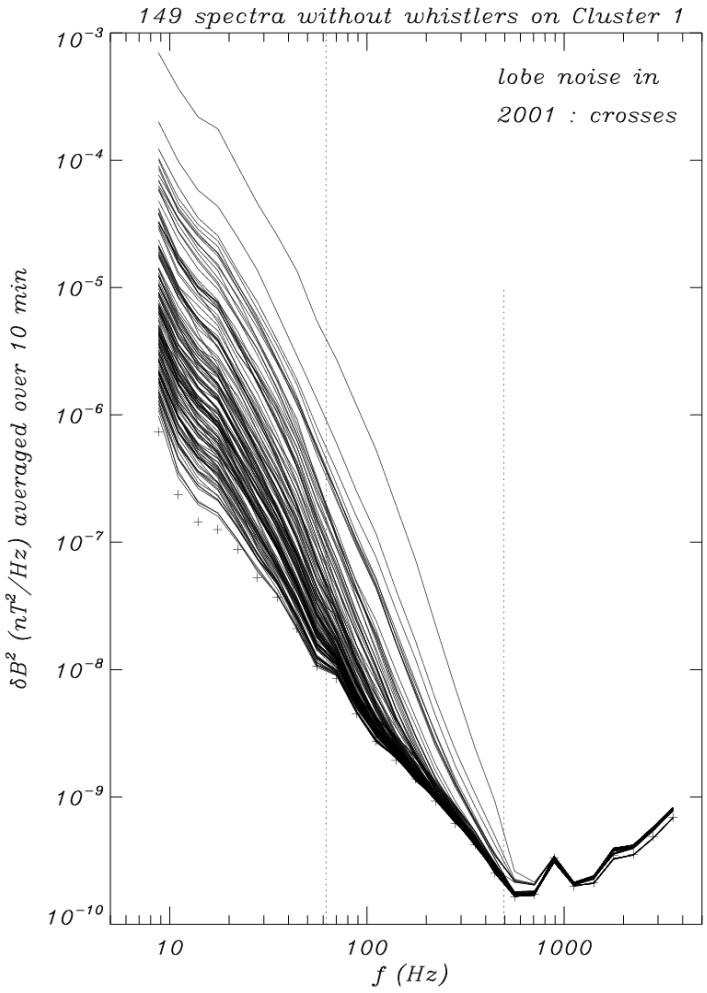


Figure 10: magnetic spectra for different intensities showing that at frequencies below 18 Hz for S/C 1 there are instrumental effects in the calibration (artificial peak).

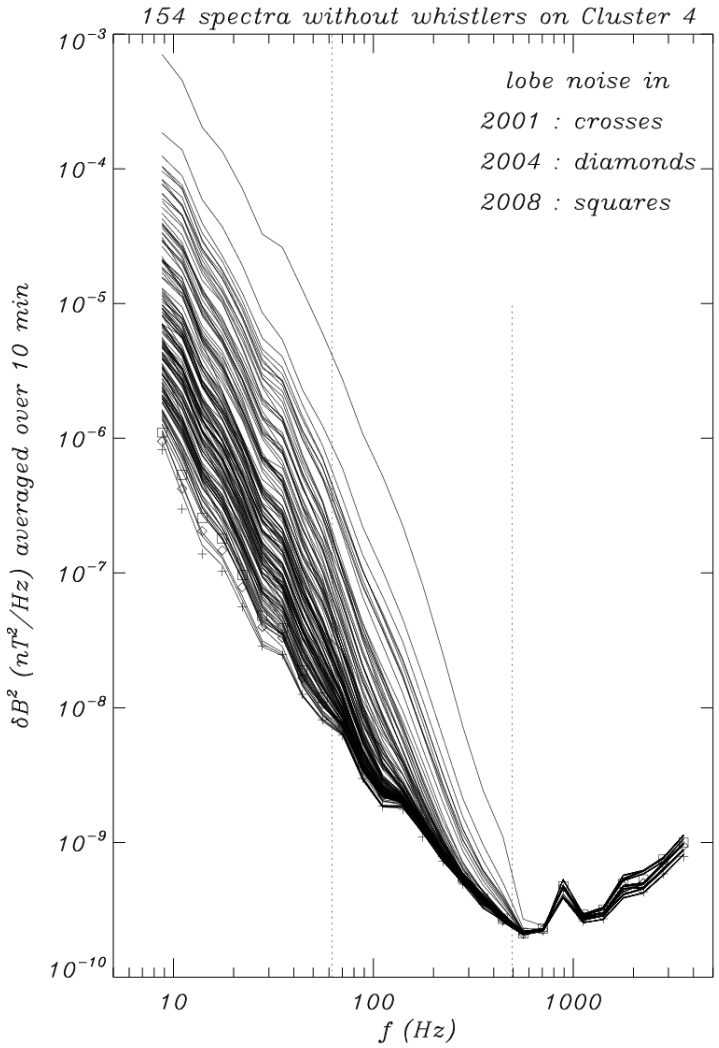


Figure 11 Same as s figure 10 for S/C 4. Here the user has to be cautious with potential peaks below 35 Hz.

6.3.4 Warning considering electric field measurements and related parameters (PVSIGN)

For the use of parameters calculated from the measurement of **ELECTRIC FIELD**, the main concern is the partial failure of EFW booms as metionned in §3 where table 3 gives periods of potentially invalid measurements. Some more details are given below.

For STAFF SA electric field measurements, one should not worry about Whisper active modes. During active modes of Whisper, only the 3 x B coefficients of the matrix are calculated on board, thanks to a careful synchronisation by DWP.

STAFF SA electric components may be affected by the EFW probe failures on some of the spacecraft (see table 3). The STAFF SA onboard despin doesn't permit to get rid of this problem and thus the 2 despun components telemetry data are affected. After the failure, the electric antenna may be saturated, but once EFW has commanded the failed probe into density mode, i.e. set the potential to V=0, the quality is good again, but the sensitivity is decreased.
For one proble failure, the underestimation of the electric power is about one third of the total power, whereas for 2 probes failures the power is underestimated by a factor of 2.

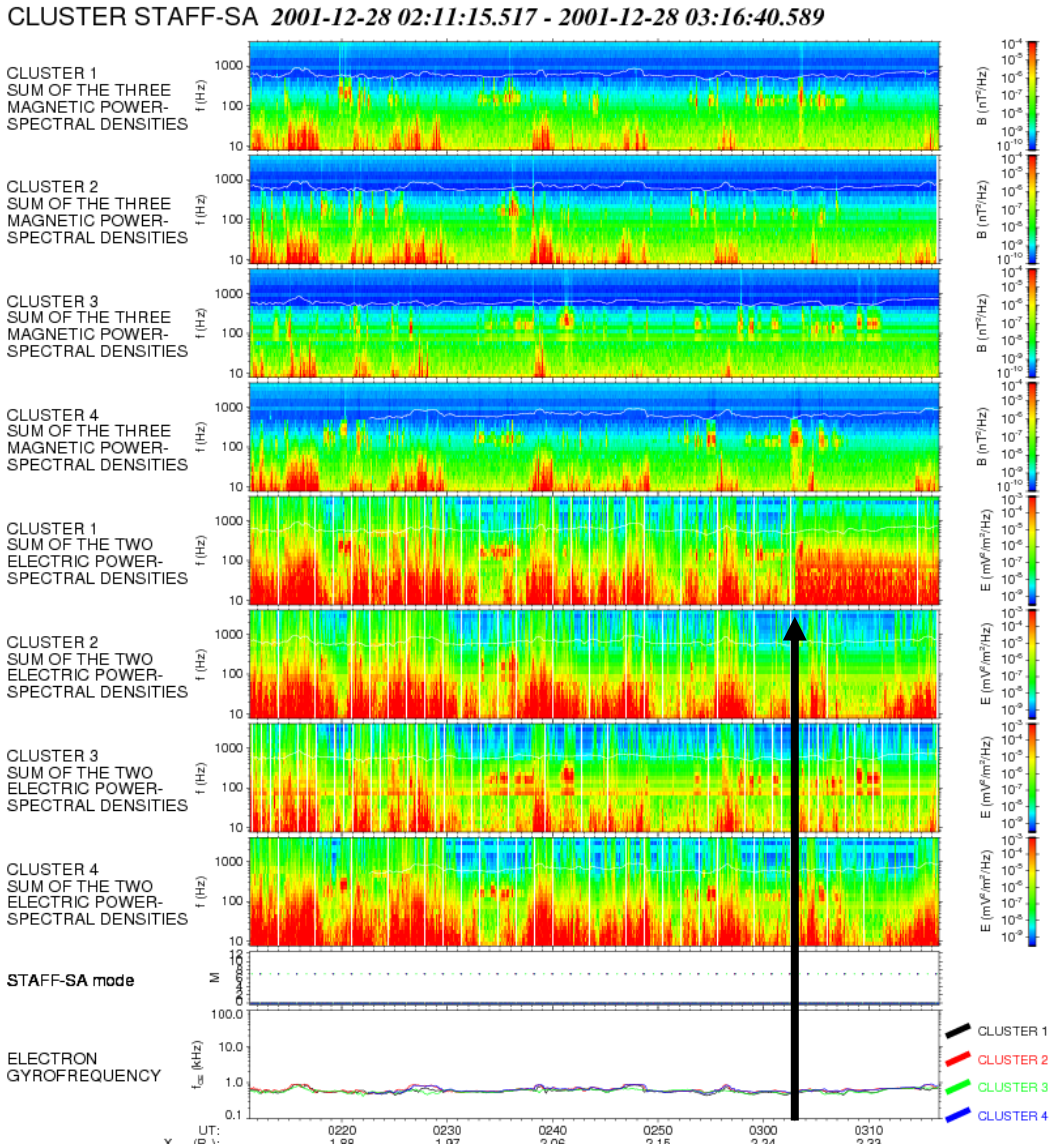


Figure 12. Failure of SC1 probe 1 at 03:02. One can see the sudden saturation of the signal.

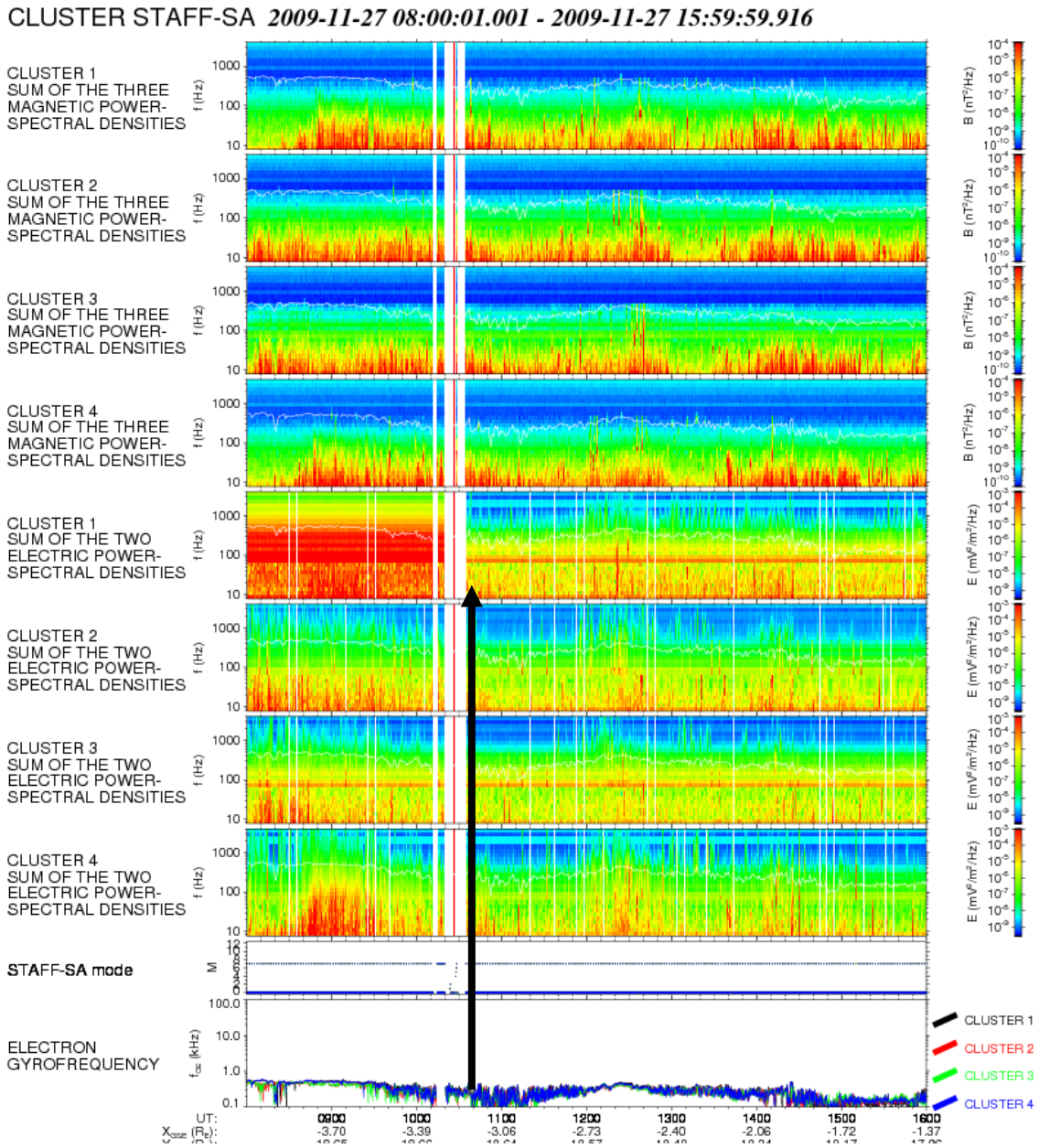


Figure 13 Recovery of E field measurements by putting the failed SC 1 probe 4 in density mode (V=0). SC1 E data change after 10:20 from saturated to behaviour comparable to other S/C

The following table gives the details of EFW operations following probe failures and data quality.

S/C	Failed probe	Failure date	Density mode implementation	Time interval	STAFF SA E data quality
C1				2001-01-01 – 2001-12-27	4
	P1	2001-12-28 03:02:57		2001-12-28 – 2002-01-27	0
			2002-01-27	2002-01-27 - 2007-06-12	2 a
				2007-06-13	XX
				2007-06-14 – 2009-04-18	2a
	P4	2009-04-19 07:29:00		2009-04-19 - 2009-05-10	0 *
				2009-05-10 -2009–10–14	2a
	P4	2009-10-14 07:00:00		2009-10-14 - 009-11-28	0
			2009-11-28	2009-11-28 - present	2b
C2				2001-01-01 - 2007-05-13	4
	P1	2007-05-13		2007-05-13 - 2007-06-23	0
			2007-06-23	2007-06-23 - present	2a
C3				2001-01-01 - 2002-07-28	4
	P1	2002-07-29 09:06:59		2002-07-29 - 2002-08-09	0
			2002-08-09	2002-08-09 - present	2a
C4				2001-01-01 - present	4

Table 5
EFW Operations and STAFF E component quality

4 : good quality
2 : no saturation - caution to absolute values :
2a :one probe is set to zero (density mode, V=0) ; power underestimated : ~0.625 of the power in $mV^2\ m^{-1}\ Hz^{-1}$
2b : 2 probes are set to zero : power underestimated by a factor of 2 (~0.5 of the power in $mV^2\ m^{-1}\ Hz^{-1}$)
0: one component saturates; do not consider using STAFF SA electric component or E field deduced parameters (Poynting Vector component)
0* : many successive operations
XX : special tests; be cautious

6.3.5 Warning considering the use of STAFF SA PPP (Polarization and Propagation Parameters)

Warnings given above, in particular in what concerns electric field measurements, are applicable. One should look at table 5 for data validity. Quality 2 seems to be good enough in what concerns the direction of the Poynting vector. For the PPP use, some more caution has to be taken. The validity of the results depends on the amplitude of signal. Thus a threshold on the total wave power density (Magnetic or electric or both), point by point, should be used (e.g. BSUM threshold for the example presented on Figure 6 is 1.0.E-07 nT^2Hz^{-1}). Another issue is the validity of the change of frame of reference. When there are either low attitude or low FGM coverage, the PPP are not calculated, the change in MFA frame of reference being not possible. PPP data are replaced by fill values. The description of these fill values will be included in a future caveat, called UNDEFINED_MFA.

6.4 Choice between different Cluster data sets

Results of cross-calibration studies (see [5]) give the following indication for the choice of a given experiment, when performing similar measurements.

Magnetic fluctuations

Frequency range / Instrument	0.1-0.5 Hz	0.5-1 Hz	1 – 10 Hz B < 10 -4 nT^2 Hz^{-1}	1 – 10 Hz B > 10 -4 nT^2 Hz^{-1}	> 10 Hz
FGM	X	X		X	
STAFF SC		X	X	X	X
STAFF SC					X

STAFF at frequencies around spin doesn't despin the data as well as FGM. Above 1, Hz the sensitivity of STAFF instrument is better than FGM one.

WBD and STAFF

Those experiments are complementary in the frequency range 25 Hz to 4 kHz, when WBD operates in its default mode (25Hz – 9.5 KHz frequency coverage). WBD has a good frequency time resolution, with only one component (E or B), and doesn't operate the whole time but rather by periods of one hour per orbit; STAFF permits polarization studies.

Conclusion of comparisons between STAFF-SA and EFW (see ref [5])

The agreement is good while the electric fluctuations level around 8.8 Hz is larger than 6 to 10 x 10^{-4} $(mV/m)^2/Hz$. As this latter value is known to be close to the EFW experiment sensitivity, the electric PSD data, around this frequency, should be retrieved preferentially from the STAFF-SA experiment. At 70 Hz, the threshold is 10^{-4} $(mV/m)^2/Hz$.

7 References

[1] Mirioni, L. ; Cornilleau-Wehrlin, N.; Maksimovic, M.; Burlaud, C.; Robert, P. Bouzid, V. : **Cluster Active Archive: Interface Control Document. Version 3,** CAA-STA-ICD-0001, 2009. http://caa.estec.esa.int/caa/ug_cr_icd.xml

[2] Cornilleau-Wehrlin, N.; Chauveau, P.; Louis, S.; Meyer, A.; Nappa, J. M.; Perraut S.; Rezeau, L.; Robert, P.; Roux, A. and C. De Villerdary: **The cluster spatio-temporal analysis of field fluctuations (STAFF) experiment.** *Space Science Review,* **79**: 107-136, 1997.

[3] Cornilleau-Wehrlin N., Chanteur G., Perraut S. , Rezeau L. , Robert P. , Roux A. , Villedary C. de, P. Canu, Maksimovic M., Conchy, Y. de, Hubert D. , Lacombe, Lefeuvre, F., Parrot M., Pinçon, J.L. , Décréau P.M.E., Harvey C.C., Louarn Ph., Santolik, O., Alleyne H.St.C., Roth M., Chust T., Le Contel O. and STAFF team, **First results obtained by the Cluster STAFF experiment,** *Ann. Geophys.,* **21**, 437-456, 2003.

[4] **WEC Instrument User Manual**, CL-WEC-UM-002, 2009. http://caa.estec.esa.int/caa/dwp_docs.xml

[5] Calibration Report of the STAFF measurements in the cluster active archive (CAA), CAA-EST-CR-001, 2009**.** http://caa.estec.esa.int/caa/ug_cr_icd.xml

[6] CLU-CP-122-2021-CET "DECOMMUTATION STAFF-SC"

[7] CLU-CP-122-2021-CET "DECOMMUTATION STAFF-SA"

[8] Santolik O., **"Propagation Analysis of STAFF-SA Data with Coherency Tests (A User's Guide to PRASSADCO)",** LPCE/NTS/073.D, Lab. Phys. Chimie Environ./CNRS, Orleans, France, 2003. (http://os.matfyz.cz/PRASSADCO/guide.pdf)

[9] Santolik O., M. Parrot, and F. Lefeuvre, **"Singular value decomposition methods for wave propagation analysis",** *Radio Sci.,* 38 (1), 1010, doi:10.1029/2000RS002523, 2003.

8 Appendix A: Acronyms

AGC	Automatic Gain Control
BSUM	Sum of the three magnetic auto-power spectra
CETP	Centre d'études des Environnements Terrestre et Planétaires
CS	Calibrated Spectra
DWF	Decommutated Wave Form
DWP	Digital Wave Processor
EFW	Electric Field and Wave experiment
ELLSVD	Ellipticity of the polarization
ESUM	Sum of the auto-power spectra of the two electric antennae
GSE	Geocentric Solar Ecliptic
ISR2	Inverse of SR2
LPP	Laboratoire de Physique des Plasmas
MFA	Magnetic Field Aligned
PHSVD	Azymuthal Angle Value of the wave vector
POLSVD	Degree of Polarization in the polarization plane
PPP	Polarization and Propagation Parameters
PSD	Power Spectral Density
PVSIGN	Direction of the Poynting Vector component parallel to the magnetic field
SA	Spectrum Analyser
SC	STAFF Wave form data (from Search Coils only)
SM	Spectral Matrix
SR2	Spin Reference 2
SSW6RF	STAFF Sensor WEC6 Reference Frame
TCOR	Time CORorrection
TED	Software to extract instrument data from WEC science data packages and to time the data using HK data
THSVD	Polar Angle Value of the wave vector

9 Appendix B: The STAFF datasets stored in the CAA

Dataset name	Dataset title[1]	Visibility in the CAA
C?_CP_STA_AGC	Automatic Gain Control	Both Web/Command-line
C?_CP_STA_PSD	Power Spectral Density (8 Hz - 4 kHz)	Both Web/Command-line
C?_CP_STA_SM	Spectral Matrix (8 Hz - 4 kHz)	Both Web/Command-line
C?_CP_STA_PPP	Polarization and Propagation Parameters (8 Hz - 4 kHz)	Both Web/Command-line
C?_CP_STA_DWF_NBR/HBR	Magnetic Field Waveform - uncalibrated (25 or 450 Hz sampling)	Both Web/Command-line
C?_CP_STA_CS_NBR/HBR	Magnetic Field Spectra in GSE (up to 12.5 Hz (NBR)/225 Hz (HBR))	Both Web/Command-line
CL_CG_STA_SC_SPECTRO_NBR	Plot - Bz Spectral Density for all spacecraft (burst; up to 225 Hz)	Both Web/Command-line

[1] This is the title visible in the CAA web GUI for downloading

10 Appendix C: description of the Status word

<table>
<tr><th>Description</th><th colspan="2">Values</th></tr>
<tr><th></th><th>Min-max</th><th>Meanings</th></tr>
<tr><td>Step in cal</td><td>0-n</td><td>0: science mode
<table>
<tr><th>Step</th><th>Mode</th><th>Attenuation (dB)</th></tr>
<tr><td>1</td><td>CAL4</td><td>0</td></tr>
<tr><td>2</td><td>CAL4</td><td>0</td></tr>
<tr><td>3</td><td>CAL4</td><td>0</td></tr>
<tr><td>4</td><td>CAL4</td><td>0</td></tr>
<tr><td>5</td><td>CAL4</td><td>-13</td></tr>
<tr><td>6</td><td>CAL4</td><td>-26</td></tr>
<tr><td>7</td><td>CAL4</td><td>-39</td></tr>
<tr><td>8</td><td>CAL4</td><td>-52</td></tr>
<tr><td>9</td><td>CAL4</td><td>-65</td></tr>
<tr><td>a</td><td>CAL4</td><td>-78</td></tr>
<tr><td>b</td><td>CAL4</td><td>Gnd</td></tr>
<tr><td>c</td><td>CAL3</td><td>0</td></tr>
<tr><td>d</td><td>CAL3</td><td>-26</td></tr>
<tr><td>e</td><td>CAL1</td><td>0</td></tr>
<tr><td>f</td><td>CAL2</td><td>0</td></tr>
<tr><td>g</td><td>CAL1</td><td>-26</td></tr>
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<tr><td>i</td><td>CAL1</td><td>-52</td></tr>
<tr><td>j</td><td>CAL2</td><td>-52</td></tr>
<tr><td>k</td><td>CAL2</td><td>Gnd</td></tr>
<tr><td>l</td><td>CAL OFF redundant</td><td></td></tr>
<tr><td>m</td><td>CAL2</td><td>-26</td></tr>
<tr><td>n</td><td>CAL Off/On satellite</td><td></td></tr>
</table>
o: after calibration, till reset or new calibration</td></tr>
<tr><td>EFW Y boom pair</td><td>0-1</td><td>0: density mode off
1: density mode on</td></tr>
<tr><td>EFW Z boom pair</td><td>0-1</td><td>0: density mode off
1: density mode on</td></tr>
</table>

<table>
<tr><td>STAFF-SA mode description</td><td>0-f</td><td><table><tr><th>Value</th><th>Mode</th></tr><tr><td>0</td><td>NM1</td></tr><tr><td>1</td><td>NM2e</td></tr><tr><td>2</td><td>NM2b</td></tr><tr><td>3</td><td>Illegal</td></tr><tr><td>4</td><td>Emergency</td></tr><tr><td>5</td><td>Special</td></tr><tr><td>6</td><td>NM1’e</td></tr><tr><td>7</td><td>NM1’b</td></tr><tr><td>8</td><td>FM1</td></tr><tr><td>9</td><td>FM3e</td></tr><tr><td>a</td><td>FM3b</td></tr><tr><td>b</td><td>Illegal</td></tr><tr><td>c</td><td>FM2</td></tr><tr><td>d</td><td>Illegal</td></tr><tr><td>e</td><td>Illegal</td></tr><tr><td>f</td><td>Passive</td></tr></table></td></tr>
<tr><td>STAFF-SC mode</td><td>0-1</td><td>0 : SC bandwidth 10 Hz
1 : SC bandwidth 180 Hz</td></tr>
<tr><td>On-board despin (STAFF-SA)</td><td>0-1</td><td>0 : despin off
1 : despin on</td></tr>
<tr><td>WHISPER transmitter</td><td>0-1</td><td>0: off
1: active</td></tr>
<tr><td>Calibration</td><td>0-1</td><td>0: off
1: active</td></tr>
<tr><td>EFW sweep progress</td><td>0-2</td><td>0: no scanning
1: scanning
2: non synchronised block</td></tr>
<tr><td>Compression</td><td>0-2</td><td>0: nominal
1: backup
2: no compression</td></tr>
<tr><td>Phase</td><td>0-3</td><td>0:Phase calculation OK/Right Sun Pulse
1:Phase calculation OK/Sun Pulse interpolated
2:Phase=-500 / No Sun Pulse
3:Phase=-500 / No reference phase in SATT</td></tr>
</table>

Example: A status values of 00070110000, means: science mode, density mode off for EFW Y and Z, SA mode =NM1’b, SC bandwidth = 10 Hz, SA despin ON, Whisper transmitter ON, Cal off, EFW not scanning, Sc compression = nominal, Phase calculation OK/Right Sun Pulse.

11 Appendix D: Description of the Compression Error

Data are sample into 16 bits for the first record of each block, but for other records only the difference is kept, coded in 12bits. If the difference between two records is too big, we may encounter compression errors. Fortunately we know on which bit the error occurs, which allows us to maximise it.

Three compression modes are available (see Status word character #10), and may lead to one or another bit to be wrong. The maximum error is then known, see the following table (where Delta is the difference between the current record and the previous one):

	Delta (16 bits)	**Maximum Compression Error (TM counts)**	**Maximum Error (mV)**
No Compression	0-65535	0	0
Normal Compression	0-2015	0	0
	2016-65535	1024	150
Backup compression	0-511	0	0
	512-1535	1	0.15
	1536-3587	2	0.3
	3588-7447	4	0.6
	7448-65535	1024	150

The normal and backup compression are used respectively when we expect to measure “low” and “high” amplitude signals including large spin signals.